PATENT SPECIFICATION

DRAWINGS ATTACHED

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International Classification:—**H 01 j 43/00**

COMPLETE SPECIFICATION

Electron Multiplier

We, INTERNATIONAL STANDARD ELECTRIC CORPORATION, a Corporation organised and existing under the laws of the State of Delaware, United States of America, of 320 Park Avenue, New York 22, New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to electron multipliers, and more particularly to electron multipliers of disc-like shape.

One of the primary objectives of conventional electron multiplier tubes is to provide linear amplification over a wide range of input signal amplitudes. One of the major limitations in this regard is the formation of a space charge inside the tube, which repels electrons away from the anode, thereby decreasing amplification at high levels. Because of the nature of secondary emission, space charge in the vicinity of the anode is usually the limiting factor.

Additionally, such prior art multipliers in a great many instances are complicated structurally, relatively large, and not as rugged as desired for certain uses.

In accordance with the present invention there is provided an electron multiplier including a pair of parallel opposed plates of insulating material, one of the plates being centrally apertured to provide a passage for charged particles or for radiation opposite a target area on the other plate, the target area having a coating of material which is electron-emissive on impact by charged particles or by radiation, as the case may be, a continuous film of resistive material on each plate covering the whole surface facing the opposite plate except, in some embodiments, for a peripheral marginal area, the film itself having emissive properties for it to serve as an electron multiplier dynode or being coated with secondary emissive material, means for hermetically sealing off the space between the two plates at the peripheral edges thereof, an anode electrode adjacent the said peripheral edges and extending around the said space, and means for making electrical connections to the films of resistive material in such a manner that a potential gradient may be set up across each film between the periphery of the film adjacent the anode electrode and, respectively, the target area or the region opposite thereto.

Embodiments of the invention will be described with reference to the accompanying drawings, in which:—

Fig. 1 is a top plan view of one embodiment of the invention;

Fig. 2 is a cross section taken substantially along section line 2—2 of Fig. 1;

Fig. 3 is a top plan view, partially broken away for clarity, of another embodiment;

Fig. 4 is a partial cross-sectional view taken substantially along section line 4—4 of Fig. 3;

Fig. 5 is a fragmentary sectional view of a modification to the multiplier of Figs. 3 and 4; and

Fig. 6 is a fragmentary sectional view of an alternative modification.

Referring now more particularly to Figs. 1 and 2, a pair of parallel opposed plates or discs 1 and 2 of insulating material such as glass, ceramic, natural lava or the like are disposed in parallel spaced relation as shown. The disc 1 is provided with a centrally located aperture 3 opposite a target area on the opposite disc 2 fitted with a metallic sleeve 4 having a flange 5 overlying the upper surface 6 of the disc 1. The aperture 3 and sleeve 4 provide a passage for electrons projected from a source 23. On the facing surfaces 8 and 9 of the discs 1 and 2 are deposited or coated resistive film dynodes 10 and 11, respectively. These films 10 and 11 are extended around the peripheries

12 and 13 of the discs 1 and 2 and are conductively connected to terminal rings 14 and 15, respectively, suitably adhered to the outer surfaces of the two discs 1 and 2 as shown.

Encircling the peripheral portions of the films 10 and 11 and secured thereto are two rings 16 and 17, respectively, of insulating material of glass, ceramic or the like. Coaxially secured to these rings 16 and 17 is a sleeve-shaped, conductive collector or anode 18. All of the parts thus far described are secured together in hermetically sealed relation such that the space 19 between the two films 10 and 11 may be evacuated upon closure of flange 5 by a hermetic window. As Fig. 2 shows more clearly, this space 19 is of disc-like shape. A pin-like supply terminal 20 is sealed within a suitable aperture in the centre of the disc 2 as shown in conductive contact with the target area at the geometric centre of the film 11. In this position the pin 20 is axially aligned with the centre of the aperture 3 and the sleeve 4.

A power supply, such as batteries indicated generally by the numerals 21 and 22, is connected between the collector 18 as shown and the terminal 20 on the one hand and the conductive sleeve 4 on the other. The terminal rings 14 and 15 are connected to tappings on the respective power supplies. The batteries 21 and 22 are, in one embodiment of this invention, identical such that the same potential is applied between the sleeve 4 and the collector 18 as between the terminal 20 and the collector.

The structure of Figs. 1 and 2 described thus far may be enclosed within an envelope or housing (not shown) which may be evacuated. Within this housing is mounted a source of electrons 23 such as an electron gun which is capable of emitting a pencil-like electron beam 24 and of directing the same through the centre of the sleeve 4 against the centre 25 of the film 11 as shown. The gun 23 may be of conventional construction.

The films 10 and 11 are secondary emissive at a ratio greater than unity. Typical materials for such films may be aluminum oxide doped with an impurity such as molybdenum or chromium. The requirements for such films is that they be semi-conductive (resistive) yet be emissive of secondary electrons upon particle impact. Being resistive, it will be obvious that a potential gradient will be established between the centre and the outer peripheral portions of the structure, this creating a radial electric field in the space 91. Electrons or other particles or radiations entering the aperture of the sleeve 4 and striking the target area at the centre 25 of the dynode film 11 produces secondary electrons which are drawn radially outwardly toward the collector 18. The dashed lines 26 and 27 depict representative radial electron trajectories having impact points on both dynode films 10 and 11. The potentials applied, the spacing between the films 10 and 11, the resistivity and emission ratio of the film dynodes 10 and 11 determine the electron multiplication and ultimate current collected by the anode 18. Typical dimensions for a practical working embodiment of this invention lie in the vicinity of an outside diameter for the multiplier of from one to three inches, voltages for the supplies 21 and 22 of about 1000 volts, spacing between the films 10 and 11 of about 0.050 inches, and size of the aperture in the sleeve 4 of from 0.0005 to 0.200 inches.

More effective control and development of the electric field established in the space 19 is achieved by using a series of radially spaced, concentric, conductive rings for applying potentials to radially successive portions of the film dynodes 10 and 11. These rings are indicated by the numerals 28 through 32 which are recessed into companion grooves provided in the surface 8 as shown. The rings are radially spaced and are concentric about the centre 25. They are also in conductive contact with radially spaced portions of the film dynode 10 as shown. Another series of concentric rings 33 through 37 are secured in the face 9 of the disc 2 as shown, these being preferably opposite the respective rings 28 through 32. The film 11 is in conductive contact with these rings.

The voltage supplies 21 and 22 are incrementally tapped and connected to the respective rings as shown such that the rings outwardly from the centre will have successively higher dynode potentials applied thereto. Preferably, opposed rings such as rings 32 and 37 will have the same potentials applied thereto. As will now be apparent, the radial potential distribution may be accurately and precisely controlled by the potentials applied to the rings. The operation of this structure as well as the multiplication of electrons is the same as described hereinbefore.

If desired, the rings 28 through 37 may have other than circular shapes in order to achieve non-axially symmetrically fields. Also, the shape or position of the rings in the face 8 may be different than that of the rings in the face 9 to yield an axial as well as a radial field.

The embodiment of the invention illustrated in Figs. 3 and 4 is quite similar to that of Figs. 1 and 2. Two glass or the like discs 38 and 39 are peripherally sealed together in such a manner as to define a disc-like space 40 therebetween. The interior faces 41 and 42 of the discs 38 and 39, respectively, are not flat and parallel as in the case of the embodiment of Figs. 1 and 2, but instead are machined or otherwise formed into a series of concentric annular grooves 43 and 44, respectively. The grooves 43 are formed in the face 41 while the grooves 44 are formed in the face 42. Each groove 43, 44 as shown has a cross-section or

profile similar to that of a dynode in a conventional electrostatically focused multiplier structure; however, as will appear from the following discussion, other shapes may be used. All of these grooves are of substantially the same size and shape, the grooves 44, however, being radially staggered with respect to the grooves 43. As shown in Fig. 4, the crests 45 of the grooves 43 are axially aligned near the valleys 46 of the grooves 44. The disc 38 has an electron passage therethrough provided by an aperture 3 which is equipped with a metallic sleeve 4 as previously described in connection with the embodiment of Figs. 1 and 2.

Deposited or coated upon the surface 41 is a thin resistive film 47 of finely divided metal or carbon. The same kind of resistive film 48 is applied on the face 42.

A suitable secondary emissive material having an emission ratio greater than unity is deposited or otherwise applied to the valley portions of the films 47 and 48 in annular segments, one such segment being indicated by the numeral 49 and another such segment by the numeral 50. These segments are radially separated by the crests 45 of the various grooves so that the only electrical connection therebetween is that provided by the resistive films 47, 48. The material of these annular segments may be of any conventional type, silver-magnesium being typical.

In the outermost groove 51 in the disc 38 is deposited a highly conductive metallic film 52 of silver or the like which serves as the collector electrode. A pin 53 penetrating the envelope formed by the two discs 38 and 39 is conductively connected to the collector 52 for applying a supply voltage thereto. Another terminal 54 penetrates the disc 38 and makes contact with the resistive film 47 in the next to the outer groove 55, while still another terminal 56 in the disc 39 makes contact with the film 48 in the outer groove 57. The target area 58 of the surface 42 is dish-shaped as shown and is provided with a film 59 of secondary emissive material. A terminal 60 is connected between the centre of this film 59, the centre of the resistive film 48 and the negative terminal of the supply battery 61. The positve terminal of this battery is connected to terminal 56 previously described. Another unidirectional voltage supply 62 is connected between the sleeve 4 and the terminal 54 with the polarity connections as shown, and still a further supply 63 is connected between the two terminals 53 and 56. The operation of this embodiment is essentially the same as that of Figs. 1 and 2, a primary beam of electrons 24a impacting the centre of the film 59, dislodging secondaries therefrom which are drawn radially outward through the space 40 by reason of the electric field established therein through the resistance of the two films 47 and 48. The potentials applied are such that secondaries liberated by the film 59 will impact the dynode segment 49 first, secondaries from this dynode then being directed to the next radially outward dynode 50 and dislodging secondaries therefrom. This process is repeated in radially outward successive steps according to the dashed line trajectory 64 until the current is finally collected by the anode 52. While in the drawings the electron trajectory is indicated as being in a single path lying in a single plane, it will be obvious that the trajectory will be volumetric radially throughout the space 40.

While the operation of the multiplier has been explained in connection with an externally generated beam 24a of electrons, it is possible to construct and operate various embodiments of this invention as photomultipliers. An example of this is given in connection with Fig. 4. In this connection, a transparent glass plate indicated by the dashed line 65 is sealed over the opening in the sleeve 4 and the film 59 is made of photoelectric material instead of material that is only secondary emissive. Light penetrating the cover 65 and striking the photoemissive film 59 will cause liberation of electrons from the latter which will be multiplied, as already explained. Also, a photoemissive material may be applied to the underside of the cover 65 such that electrons emitted thereby may be used to impact the secondary emissive film 59 causing dislodgment of secondaries therefrom. Obviously, the space 40 must be evacuated as already explained in connection with Fig. 2.

The basic multiplier configuration of Figs. 1 through 4 may undergo certain structural modifications for the purpose of varying the operation thereof. For example, by a slight modification, the multipliers may be operated as "trackers", the forms of the invention as shown in Figs. 5 and 6 being examples. In Fig. 5, the structure thereof is identical to that of Fig. 4 with the exception that the central portion 58a of the surface 42 is elevated into the shape of a cone. The film 59a thereon has the same shape. A primary electron beam 24b off centre as shown impacting one side of the film 59a will initiate a secondary electron trajectory which is directed angularly outwardly therefrom instead of being evenly radially distributed throughout the space 40. By making the collector 52 (Fig. 4) in circumferentially separated segments, the angular position of the beam 24b can be determined.

A similar result can be achieved by the further embodiment shown in Fig. 6 wherein a pin electrode 66 is coaxially positioned in the disc 39 in axial alignment with the opening in the sleeve 4. This pin 66 is held in position by means of a glass or the like sleeve 67 hermetically sealed thereto which is in turn hermetically sealed to a metal sleeve 68 conductively connected to film 58. The secondary emissive film 59c has a clearance surrounding

the pin 66 as shown. A battery 69 is connected between the pin 66 and the sleeve 68 which in turn is connected to the resistive film 48 on the surface 58.

In operation, a beam 24c which is slightly eccentric will be deflected more in the direction of the eccentricity by the pin 66 as shown by the dashed line trajectory. The potential supplied to the pin 66 is made sufficiently negative with respect to the beam 24c to produce the deflection. Using a segmented collector as described in connection with Fig. 5, the angular position of the beam 24c can be easily determined.

Advantages residing in the disc-like geometry of the multipliers disclosed in the preceding are in part as follows. The structure is physically more compact than other multipliers, particularly in axial extent. The larger elemental volume in the outer peripheral portions of the multiplier permits greater current-handling capability. As radius increases, the volume of the multiplying space for a given increment of radius increases. In this connection, current growth is approximately exponential while volume increase is linear with radius.

In the form of the invention in Figs. 1 and 2 where the ring electrodes 28 through 37 are not used, the resistive dynode films 10 and 11 are relied upon to provide the necessary field for accelerating the electrons radially outwardly. This eliminates the need for applying incremental voltages at various points along the radius of the multiplier. The dynodes may simply be evaporated or deposited onto the preformed substrates, leading to a simpler and more rugged structure.

If the films 10 and 11 are of uniform thickness and radial resistivity, a logarithmic potential increase with radius is produced such that the electric field decreases with increased radius. This results in some reduction in allowable current density adjacent to the collector which offsets to some extent the advantages gained by the increase in multiplier volume in this same region. A linear potential increase, with radius may be achieved by varying the thickness or resistivity of the films 10 and 11 such that the electric field remains constant with radius or increases with radius to reduce the depressive effect of space charge in the peripheral region.

Certain advantages in the arrangement of Figs. 3 and 4 over the embodiment of Figs. 1 and 2 include the simplicity of fabrication and resulting greater ruggedness in the finished structure. The collector may be made as an integral part of the structure such that the two supporting discs 38 and 39 may be sealed together at the outer edges thereof. The resistivity requirement of the dynode material is not constricted to provide also for proper distribution of potential; thus providing greater freedom in materials and design, and the number of impacts and integrated time of flight is held relatively constant, thereby improving linearity and minimizing time distortion.

The preceding embodiments can be made optically transparent so as to transmit light. In this respect, not only would the supporting discs 1 and 2 (Fig. 2, for example) be transparent but also the electrodes and the resistive and dynode materials.

Additionally, instead of using, in the arrangement of Fig. 2, a single film which serves both resistive and secondary-emissive functions, two superposed layers may be used, the substrate being of resistive material and the outer one being of secondary emissive material. Thus, the functions of potential distribution and secondary emission yield would be sepagated.

In the event an output signal voltage is desired, a load resistor is connected in series with the collector lead.

While the invention has been disclosed primarily in conjunction with electrons, it will be understood that electron multiplication can be initiated by alpha, beta and gamma radiation as well as ions.

WHAT WE CLAIM IS:—

1. An electron multiplier including a pair of parallel opposed plates of insulating material, one of the plates being centrally apertured to provide a passage for charged particles or for radiation opposite a target area on the other plate, the target area having a coating of material which is electron-emissive on impact by charged particles or by radiation, as the case may be, a continuous film of resistive material on each plate covering the whole surface facing the opposite plate except, in some embodiments, for a peripheral marginal area, the film itself having emissive properties for it to serve as an electron multiplier dynode or being coated with secondary emissive material, means for hermetically sealing off the space between the two plates at the peripheral edges thereof, an anode electrode adjacent the said peripheral edges and extending around the said space, and means for making electrical connections to the films of resistive material in such manner that a potential gradient may be set up across each film between the periphery of the film adjacent the anode electrode and, respectively, the target area or the region opposite thereto.

2. An electron multiplier as claimed in claim 1 wherein the surface of each plate on the side facing the opposite plate has spaced-apart grooves filled with conductive material for making contact with different regions of the film resistive material, and each groove is associated with a respective terminal lead sealed through the plate and contacting the conductive material in the groove.

3. An electron multiplier as claimed in claim 1 or 2 wherein each film of resistive material extends over the edge of its plate and onto the reverse side of the plate to provide a termi-

nal contact area, an insulating collar is sealed to the film around each plate, and the said anode electrode is sealed to the collar on each plate and maintains the plates in position relative to one another.

4. An electron multiplier as claimed in claim 1 wherein the surface of each plate opposing the other plate is provided with a set of concentric grooves, the film of resistive material is not itself significantly emissive and the secondary emissive material is in the form of coatings extending along the valleys of the grooves but not between adjacent grooves, the contour of the grooves, including the film of resistance material and coating of secondary emissive material thereon, and the position of the grooves on one plate with respect to those on the other being such that, during operation of the device, electrons are electrostatically focused from groove to groove across the space between the two plates from the centre of the device to the anode electrode.

5. An electron multiplier as claimed in claim 4 wherein the peripheral edges of the plates are formed with rims projecting towards one another, the two rims are hermetically sealed together to define and seal the outer boundary of the space between the plates, the outermost of the concentric grooves of the pair of plates contains a coating of conductive material providing the anode electrode, and a terminal connection to the anode electrode is sealed through the wall of the enclosure formed by the two plates.

6. An electron multiplier as claimed in claim 5, wherein the said target area is formed as a depression in the surface of the said other plate, the film of resistive material extends under the coating of emissive material on the target area, the last mentioned coating does not extend beyond the rim of the depression and a terminal lead sealed through the plate contacts the resistive film within the depression.

7. An electron multiplier as claimed in claim 5, constructed and arranged for excitation by charged particles, wherein the said target area is formed as a convex portion on the surface of the said other plate and is covered by the resistive film and by a localised coating of secondary emissive material, the arrangement being such that a primary beam of charged particles impinging eccentrically on the convex portion generates an electron beam spreading out towards the anode electrode with a maximum intensity in the radial direction corresponding to the eccentricity of the primary beam, and wherein the anode electrode is subdivided into separate sectors angularly disposed around the enclosure between the plates.

8. An electron multiplier as claimed in claim 5, constructed and arranged for excitation by charged particles, wherein the said target area is centrally apertured and is formed in but does not extend beyond the rim of a concavity in the surface of the said other plate, a conductive sleeve lining the aperture makes contact with and provides a terminal connection for the resistive film on the plate, the sleeve is filled with a plug of insulating material carrying a central rod which projects from both ends, and the anode electrode is divided into sectors angularly disposed around the centre of the device, the arrangement being such that, during operation, charged particles deflected away from the central rod in any given direction and impinging on the target area give rise to a beam of electrons having a predominant angular distribution in that radial direction.

9. An electron multiplier as claimed in any preceding claim wherein the passage in the said one of the plates opposite the target area is lined with a conductive sleeve contacting the film of resistive material on one side of the plate and extending over a portion of the other side to form a terminal connection.

10. An electron multiplier as claimed in claim 9 in its dependency on any one of claims 1 to 6 wherein the last mentioned conductive sleeve is closed by a plate transparent to radiation and the target area has a photoemissive coating.

11. An electron multiplier as claimed in any one of claims 1 to 9, including a source of primary electrons arranged for projecting a beam of electrons onto the said target area.

12. An electron multiplier as claimed in claim 9 wherein the last mentioned conductive sleeve is closed by a plate transparent to radiation, which plate is coated with photoemissive material on its side facing the target area.

13. An electron multiplier substantially as described herein with reference to Figs. 1 and 2 of the accompanying drawings.

14. An electron multiplier substantially as described herein with reference to Figs. 3 and 4 of the accompanying drawings.

15. A modification of an electron multiplier as claimed in claim 14 substantially as described herein with reference to Fig. 5 or to Fig. 6 of the accompanying drawings.

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Chartered Patent Agent,
For the Applicants.

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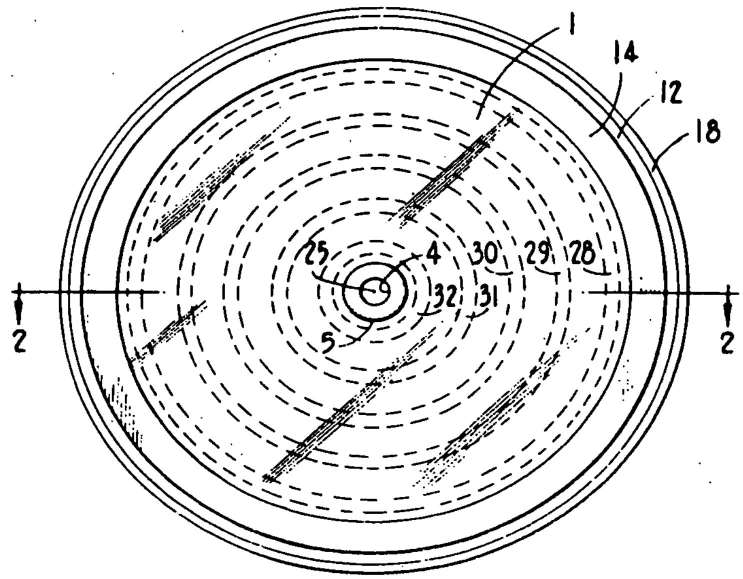
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FIG. 1

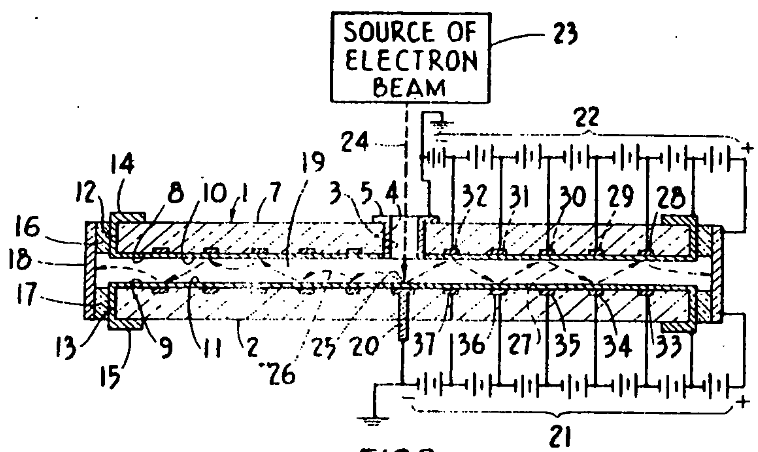
SOURCE OF ELECTRON BEAM
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FIG. 2

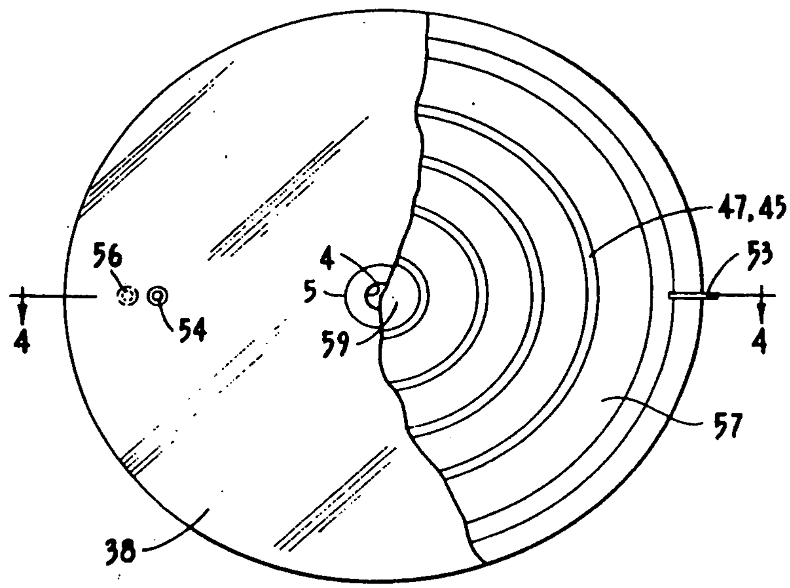
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FIG. 3

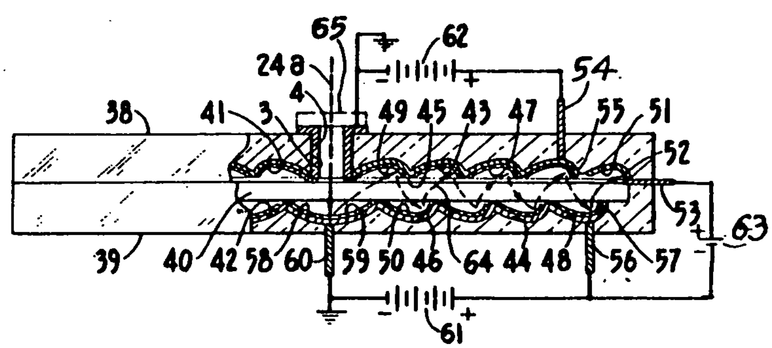
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FIG. 4

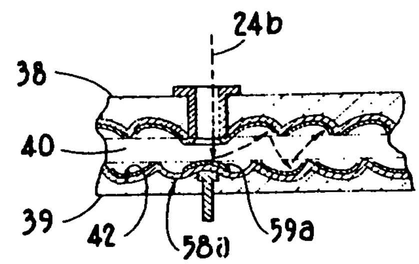

FIG. 5

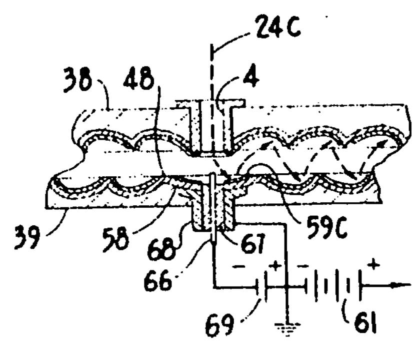

FIG. 6